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Effect of Soaking Time and Roasting Temperature on Quality of Sorghum Flakes

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ABSTRACT

Millets offer unique advantage for health being rich in micronutrients, particularly minerals and B vitamins as well as nutraceuticals. Flaking of millets has been successfully attempted adapting the normal cereal flaking methods using roller flaker. An attempt has been made to see the effect of soaking time and roasting temperature on flaking of sorghum. A total of 40 experiments were conducted by a combination of treatments to sorghum grain, namely, soaking in cold water for 12, 18, 24, 30 and 36 h, machine roasting at 200, 210 and 220 °C, open pan roasting at 125±2 °C and roller machine parameters, namely, speed of rollers at 60 rpm and 80 rpm and gap between the rollers at 0.1 mm. The highest yield of 93.27 % percent was obtained for flakes processed by 36 h soaking, open pan roasting at 125±2 °C and 60 rpm roller speed and lowest yield of 59.30 % for 24 h soaking, open pan roasting at 125±2 °C and 80 rpm roller speed. It was also observed that the yield obtained for different treatments was more at 60 rpm roller speed than at 80 rpm. It was observed that a moisture content of 9.20 % (wb) for flakes processed by 36 h soaking, open pan roasting at 125±2 °C and 60 rpm roller speed gave the highest and a lowest moisture content of 7.08 % (wb) for flakes processed by 24 h soaking, open pan roasting at 125±2 °C and 80 rpm roller speed. It was observed that a bulk density of 0.352 g/ml for flakes processed by 24 h soaking, open pan roasting at 125±2 °C and 80 rpm roller speed gave the highest and a bulk density of 0.317 g/ml for flakes processed by 36 h soaking, open pan roasting at 125±2 °C and 60 rpm roller speed gave the lowest. It was observed that the water absorption capacity of 106.607 g/100 g for flakes processed by 24 h soaking, open pan roasting at 125±2 °C and 60 rpm roller speed gave the highest and the water absorption capacity of 52.477 g/100 g for flakes processed by 36 h soaking, open pan roasting at 125±2 °C and 80 rpm roller speed gave the lowest. It was observed that a thickness of 0.947 mm for flakes processed by 36 h soaking, open pan roasting at 125±2 °C and 80 rpm roller speed gave the highest and a thickness of 0.757 mm for flakes processed by 24 h soaking, open pan roasting at 125±2 °C and 60 rpm roller speed gave the lowest. Based on the highest yield and lowest bulk density of flakes, it can be concluded that 36 h soaking time, pan roasting at 125±2 °C, roller flaking at 60 rpm and with 0.1 mm gap between the rollers were the process and machine parameters optimized.

Key words: *Bulk density, Sorghum, Yield, Thickness, Water absorption capacity,*

India is the second largest producer of sorghum in the world with 7.5 million tons during 2017-18. (https://www.worldatlas.com). The sorghum crop is primarily produced in Maharashtra, Karnataka and Andhra Pradesh, Madhya Pradesh, Gujarat and Rajasthan are the other states producing sorghum. Sorghum is considered as coarse grain due to the presence of outer fibrous bran of seed. Sorghum is poor in lysine but rich in leucine (Dayakara Rao *et al*., 2007). Millets offer unique advantage for health being rich in micronutrients, particularly minerals and B vitamins as well as nutraceuticals. Flaking of millets has been successfully attempted adapting the normal cereal flaking methods using roller flaker. Since, millets are small seeded grains, the flakes from these will hydrate easily and may serve as quick cooking cereals. Non-availability of appropriate sorghum flaking machinery at a reasonable price is one of the major constraints for initiating small/medium scale manufacture of sorghum flakes in rural farming areas. To facilitate rural entrepreneurs a low capacity roller flaking machine was developed at College of Agricultural Engineering and the same machine was used in the present study. An attempt has been made to see the effect of soaking and roasting on flaking of sorghum.

Mannuramath and Yenagi (2015) studied the optimization of hydrothermal treatment for little millet grains (*Panicum miliare*) to improve the milling quality. Chavan *et al*. (2015) undertook a study with an objective to standardize procedures for preparation of flakes from sorghum, to identify the best genotype for preparation of flakes and to study the nutritional quality parameters of flakes and their products. Tamil Nadu Agricultural University (2013) developed a method of flaking of sorghum in which pearled grain was soaked for 2 h in water, steamed (pressure cooked for 15 min), dried at 70 °C for 1 h in a cabinet drier and pressed between rotating rollers having a specific clearance which determines the flake thickness. The flakes thus obtained were subjected to drying for 45 min in solar drier, graded and packed. Dayakar Rao (2012) processed sorghum flakes by soaking sorghum grain in water for overnight at room temperature, air drying for 3 h, roasting at

200 °C for 5 minutes in a roaster, flaking in edge runner, sieving, cooling and packing. Dharmaraj and Malleshi (2011) investigated the changes in carbohydrates, proteins and lipids of finger millet after hydrothermal processing. Gates *et al.* (2008) studied the interaction of heat-moisture conditions and physical properties in oat processing: flake quality. Panasiewicz (2007) studied the influence of hydrothermal processes on final moisture content of barley grain. Anderson (1994) studied the effects of tempering and steaming on flaking of sorghum. An attempt has been made to see the effect of soaking and roasting on flaking of sorghum as there is no much literature available.

MATERIAL AND METHODS

The unit operations involved in sorghum processing for flaking are cleaning, soaking, roasting, flaking, drying and packing. A total of 40 experiments were conducted by giving hydrothermal treatments to sorghum grain as per the design of experiments. The process flow chart for preparation of sorghum flakes is given in Fig.1.

The raw material *i.e*. sorghum, *Mahalakshmi*-946, a popular white variety was procured from the farmers of Tenali and Narasaraopet mandal areas of Guntur district, Andhra Pradesh.

The sorghum grains were cleaned and destoned by using a cleaner cum destoner machine. The initial moisture content of sorghum was found to be 10.5% (wb). Cleaned sorghum was washed thoroughly in cold soft water for removing the light and dusty material adhered to the grain. In each batch operation, a 4 kg sample of cleaned sorghum was washed thoroughly in cold water and rinsed. The washed sorghum was soaked in cold water for 12, 18, 24, 30 and 36 h duration. Conditioning of the soaked samples were done at ambient temperature for 30 min by spreading them on a muslin cloth. All the soaked and conditioned sorghum samples were subjected to roasting operation at each 200, 210 and 220 °C by using mechanical roaster, roasted in open pan at 125±2 °C. All the roasted sorghum samples were subjected to flaking operation by using developed roller flaking machine. The gap between the rollers was maintained as 0.1 mm and at 60 rpm and 80 rpm of roller speed (Fig. 2). Flake samples of each batch were subjected to drying operation at 50 °C by using a tray drier for a period 6-8 h till equilibrium condition was attained. Moisture contents of the dried samples were determined. All the dried sorghum flake samples were subjected to grading and packed in Low density polyethylene (175 gauge) or Polypropylene (160 gauge) bags and stored at ambient conditions (Fig. 3).

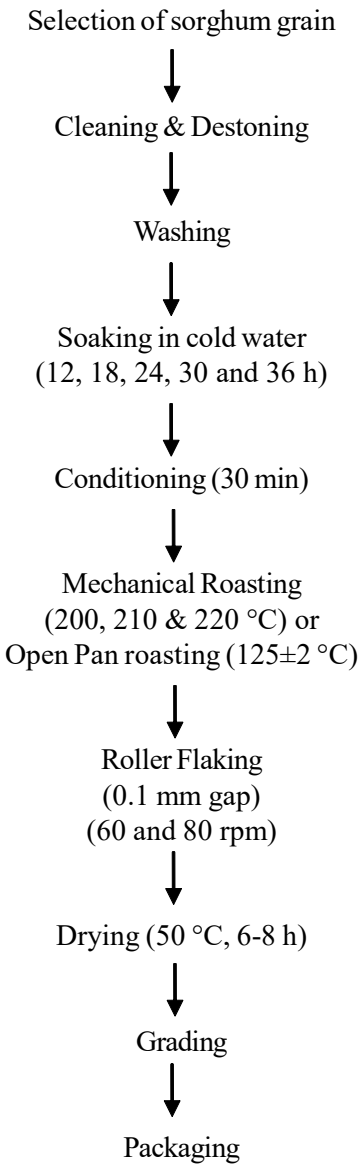

Fig1. Flow chart for processing of sorghum flakes

Quality attributes of sorghum flakes

Sorghum flake yield and its quality is assessed in terms of bulk density, water absorption capacity, thickness and moisture content (Sailaja, 1992)

Bulk Density of Sorghum Flakes

Volume of 100 g flakes was measured using a graduated measuring cylinder. The bulk density of flakes was calculated using Equation 1 and expressed in g mL^{-1}.

$$\text{Bulk density} = \frac{Mass\ of\ sample\ (g)}{Volume\ of\ sample\ (mL)} \quad \ldots\ldots 1$$

Yield of Sorghum Flakes

Flakes were passed through 8/64" round (commercial) sieve to separate brokens and powder. The yield of flakes is expressed as percentage.

Table 1. Effect of soaking duration and roasting temperature on yield of sorghum flakes processed at 60 and 80 rpm roller speed

File Version	11.0.3.0		
Study Type	Factorial	Sub type	Randomized
Design Type	Full Factorial	Runs	120
Design Model	2FI	Blocks	No Blocks
Center Points	0	Build Time (ms)	4

Response	Name	Units	Observations	Analysis	Minimum	Maximum	Mean	Std. Dev.	Ratio	Transform	Model
R1	Process Yield	%	120	Factorial	0.56	93.31	14.55	28.77	166.63	None	2FI
R2	Moisture Content	%	120	Factorial	4.54	9.24	6.76	1.32	2.04	None	Reduced 2FI

A	Soaking Time	h	Categoric	12	36	Levels:	5
B	Roasting Temperature	°C	Categoric	125	220	Levels:	4
C	Roller Speed	rpm	Categoric	60	80	Levels:	2

Table 2. ANOVA for process yield

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	98453.23	27	3646.42	15038.3	< 0.0001	significant
A-Soaking Time (h)	12228.50	4	3057.12	12607.99	< 0.0001	
B-Roasting Temp. (°C)	53339.99	3	17780.00	73327.06	< 0.0001	
C-Roller Speed (rpm)	76.94	1	76.94	317.33	< 0.0001	
AB	32645.69	12	2720.47	11219.59	< 0.0001	
AC	6.49	4	1.62	6.69	< 0.0001	
BC	155.61	3	51.87	213.92	< 0.0001	
Residual	22.31	92	0.24			
Lack of Fit	21.39	12	1.78	154.95	< 0.0001	significant
Pure Error	0.92	80	0.01			
Cor Total	98475.54	119				

The Model F-value of 15038.30 implied that the model was significant. It is significant at 1 % probability level.

Table 3. ANOVA for moisture content of sorghum flakes processed by soaking, roasting and roller flaking

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	206.23	24	8.59	1031.75	< 0.0001	significant
A-Soaking Time (h)	177.49	4	44.37	5327.8	< 0.0001	
B-Roasting Temp. (°C)	21.71	3	7.24	868.86	< 0.0001	
C-Roller Speed (rpm)	4.56	1	4.56	546.94	< 0.0001	
AB	2.22	12	0.19	22.21	< 0.0001	
AC	0.26	4	0.06	7.68	< 0.0001	
Residual	0.79	95	0.01			
Lack of Fit	0.24	15	0.016	2.32	0.0086	significant
Pure Error	0.55	80	0.0069			
Cor Total	207.02	119				

The Model F-value of 1031.75 implied the model was significant. It is significant at 1 % probability level.

Table 4. Sorghum sample treatments and flake sample codes

Treatment	Treatment	Sample code of Sorghum flakes
T_1	24 h soaked, open pan roasted at 125±2 ºC, 0.1 mm roller gap and 60 rpm roller speed	A
T_2	24 h soaked, open pan roasted at 125±2 ºC, 0.1 mm roller gap and 80 rpm roller speed	B
T_3	30 h soaked, open pan roasted at 125±2 ºC, 0.1 mm roller gap and 60 rpm roller speed	C
T_4	30 h soaked, open pan roasted at 125±2 ºC, 0.1 mm roller gap and 80 rpm roller speed	D
T_5	36 h soaked, open pan roasted at 125±2 ºC, 0.1 mm roller gap and 60 rpm roller speed	E
T_6	36 h soaked, open pan roasted at 125±2 ºC, 0.1 mm roller gap and 80 rpm roller speed	F

Table 5. Yield of sorghum flakes obtained by different treatments

Treatment	Yield of flakes (%)			Mean	SD
	Rep 1	Rep 2	Rep 3		
T_1	68.20	68.60	67.80	68.20	0.40
T_2	59.30	59.80	58.80	59.30	0.50
T_3	91.73	91.69	91.73	91.72	0.02
T_4	87.23	87.27	87.19	87.23	0.04
T_5	93.27	93.23	93.31	93.27	0.04
T_6	89.74	89.70	89.78	89.74	0.04

Table 6. Final moisture content of sorghum flakes obtained by different treatments

Treatment	Moisture content of flakes (% wb)			Mean	SD
	Rep 1	Rep 2	Rep 3		
T_1	7.38	7.30	7.46	7.38	0.08
T_2	7.08	7.00	7.16	7.08	0.08
T_3	8.34	8.38	8.30	8.34	0.04
T_4	7.90	7.86	7.94	7.90	0.04
T_5	9.20	9.24	9.16	9.20	0.04
T_6	8.70	8.60	8.80	8.70	0.10

Table 7. Bulk density of sorghum flakes obtained by different treatments

Treatment	Bulk density (g/mL)			Mean	SD
	Rep 1	Rep 2	Rep 3		
T_1	0.327	0.325	0.326	0.326	0.001
T_2	0.353	0.352	0.351	0.352	0.001
T_3	0.323	0.322	0.324	0.323	0.001
T_4	0.338	0.337	0.339	0.338	0.001
T_5	0.315	0.318	0.317	0.317	0.002
T_6	0.325	0.326	0.326	0.326	0.001

Table 8. Water absorption capacity of sorghum flakes obtained by different treatments

Treatment	Water absorption capacity (g/100g)			Mean	SD
	Rep 1	Rep 2	Rep 3		
T_1	106.59	106.78	106.45	106.61	0.17
T_2	102.90	102.84	102.99	102.91	0.08
T_3	90.00	89.73	89.51	89.74	0.25
T_4	86.66	86.51	86.46	86.54	0.11
T_5	83.81	83.51	84.00	83.77	0.24
T_6	75.16	75.02	75.40	75.19	0.19

Table 9. Thickness of sorghum flakes obtained by different treatments

Treatment	Thickness of flakes (mm)			Mean	SD
	Rep 1	Rep 2	Rep 3		
T_1	0.73	0.78	0.76	0.76	0.03
T_2	0.85	0.85	0.87	0.86	0.01
T_3	0.76	0.80	0.83	0.80	0.04
T_4	0.88	0.90	0.89	0.89	0.01
T_5	0.75	0.83	0.81	0.80	0.04
T_6	0.85	1.01	0.98	0.95	0.09

Fig 2. Developed sorghum roller flaking machine in operation

Fig. 3. Sorghum flakes stored in LDPE and PP packaging material

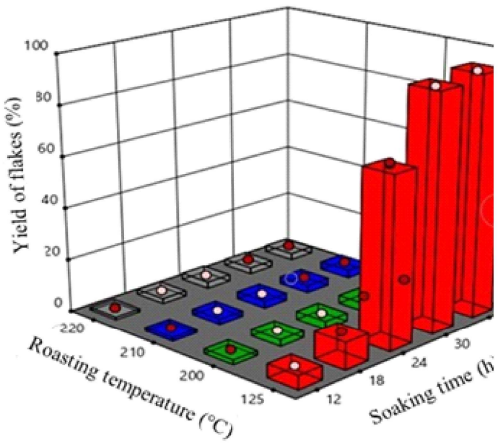

Fig 4. Effect of soaking time and roasting temperature on yield of sorghum flakes at 60 rpm roller speed

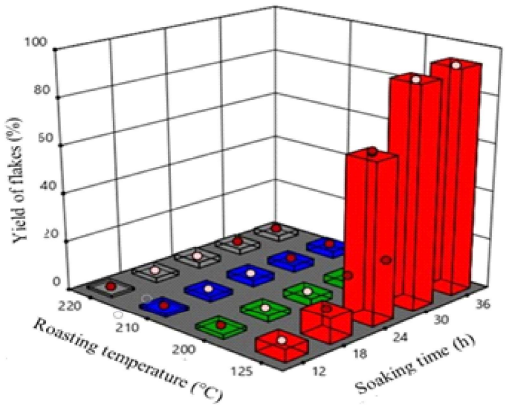

Fig 5. Effect of soaking time and roasting temperature on yield of sorghum flakes at 80 rpm roller speed

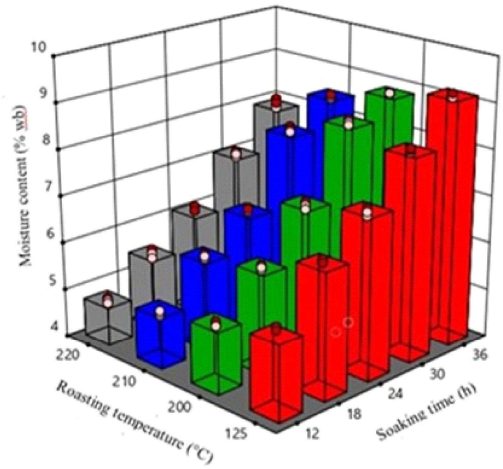

Fig 6. Effect of soaking time and roasting temperature on moisture of sorghum flakes at 60 rpm roller speed

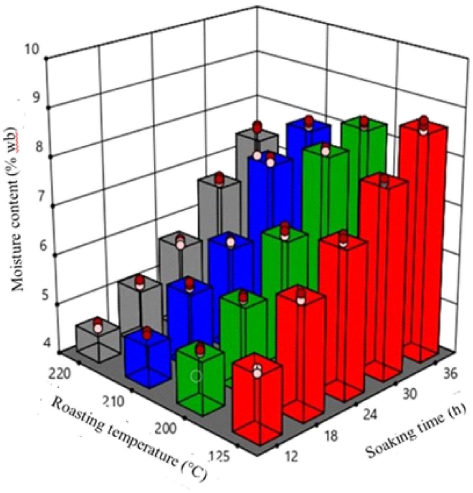

Fig7. Effect of soaking time and roasting temperature on moisture of sorghum flakes at 80 rpm roller speed

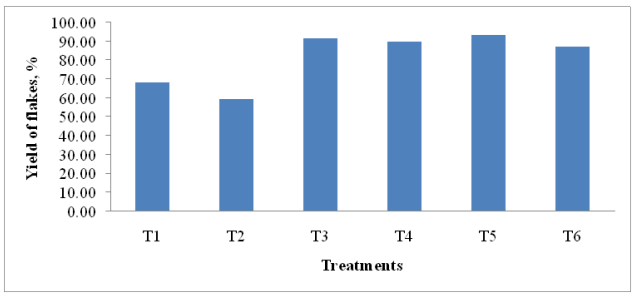

Fig 8. Yield of sorghum flakes processed by different treatments

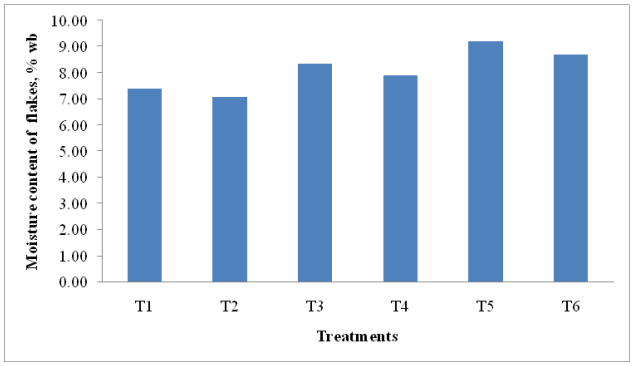

Fig 9. Final moisture content of sorghum flakes of different treatments

Water Absorption Capacity of Sorghum Flakes

Water absorption capacity of sorghum flakes was measured by weighing the water uptake of 2 g of flakes at room temperature for 10 minutes. The values were expressed as g /100g of flakes.

Thickness of Sorghum flakes

A sample of 20 sorghum flakes was selected at random and its thickness at three locations of each flake was measured using Mitutoyo Digimatic Calipers (Japan) with least count 0.01 mm.

Moisture Content of Sorghum Flakes

Moisture content of the flakes was determined by Oven drying method (AOAC, 2000). About 2 g ground flake sample was taken in an emptied petri dish which was weighed before and spread evenly for uniform drying. Petri dish was placed in an oven (Yorko Make) at 130±1 °C with lid open for 1 h which was cooled in a desiccator with closed lid for 15 min later. Weight of the sample was taken when weight remained constant.

The percent yield and moisture content of flakes obtained were statistically analysed by using Design Expert Package (V 11.3).

RESULTS AND DISCUSSION

A total of 40 experiments were conducted by giving hydrothermal treatments to sorghum grain as per the design of experiments having a different combinations of soaking in cold water for 12, 18, 24, 30 and 36 h, machine roasting at 200, 210 and 220 °C, open pan roasting at 125±2 °C and roller flaking machine parameters namely speed of rollers at 60 rpm and 80 rpm and gap between the rollers at 0.1 mm. The percent yield of thin flakes and moisture content of flakes obtained in triplicates was analysed using Design Expert Package (Version 11.3) and values are presented in Tables 1 through 3. The six soaking and roasting treatments were selected as T_1, T_2, T_3, T_4, T_5, T_6, and sorghum flake samples were coded as A, B, C, D, E, and F respectively as shown in the Table 4.

Effect of Soaking Duration and Roasting Temperature on Yield of Sorghum Flakes Processed at 60 and 80 RPM Roller Speed

The percent yield of sorghum flakes obtained by different treatment combinations of soaking duration 12, 18, 24, 30 and 36 h; machine roasting temperatures 200, 210 andb 220 °C; open pan roasting temperature 125±2 °C and 60 rpm and 80 rpm roller speeds with 0.1 mm gap between the rollers are presented. It was observed that the yield of flakes obtained was more at open pan roasting temperature of 125±2 °C as compared to machine roasting temperatures 200, 210 and 220 °C for different duration of soaking. The yield percent of sorghum flakes at 60 rpm roller speed are presented in Fig. 4. It was observed that the percent yield of flakes increased with soaking time and it decreases with increase of roasting temperatures at 60 rpm roller speed.

It was observed that the highest yield obtained for a combination of soaking time 36 h, roasting temperature of 125±2 °C and 60 rpm roller speed was 93.27 %. However, the difference of yield of sorghum flakes at 30 h and 36 h, it was only 1.54 %, but the difference of yield between 24 h and 30 h was found to be 23.52 %, at the same temperature and roller speed. Hence, it was recommended that 36 h soaking time can be taken as optimum.

The yield percent of sorghum flakes at 80 rpm roller speed are presented in

Fig. 5. It was observed that for soaking period of 36 h, the yield was 89.74 %. However, the difference of yield of sorghum flakes at 30 h and 36 h, it was only 2.51 %, but the difference of yield between 24 h and 30 h was found to be 27.93 %. Hence, it was recommended that 36 h soaking time can be taken as optimum.

The reason for the highest yield of flakes could be due to higher moisture contents of pan roasted grain which are above 30 % (wb) as compared to moisture contents of machine roasted grains which are below 25 % (wb). The higher moisture content of roasted grains above 30% (wb) might have contributed for the complete gelatinization of starch at open pan roasting temperature of 125±2 °C which resulted in the flakes with better expansion and higher yield. The higher temperatures used in machine roasting have resulted in lowering the moisture content of roasted grain and imparting hard texture to the flakes.

Moisture Content of Sorghum Flakes

The results of final moisture content of sorghum flakes obtained by different treatment combinations of soaking time (12, 18, 24, 30 and 36 h) and roasting temperatures (125, 200, 210 and 220 °C) at 60 rpm roller speed was presented in Fig. 6. Similar results were obtained for the same treatment combination for a roller speed of 80 rpm. It was presented in Fig. 7. It was observed that moisture content obtained for different treatment combinations at 60 rpm was more compared to 80 rpm roller speed.

In general, the moisture content was increased with increase of soaking duration and decreased with increase of roasting temperatures. The maximum moisture content was observed for 36 h soaking for open pan roasting followed by 200 °C roasting temperature. The minimum moisture content was

observed for a treatment combination of 12 h soaking duration and roasting temperature of 220 °C. The maximum moisture content of 9.24% (wb) was observed for 36 h soaked and open pan roasted sorghum flakes processed at 60 rpm roller speed followed by 8.80% (wb) for the sorghum flakes processed by the same conditions and at 80 rpm roller speed. The minimum moisture content of 4.54% (wb) was observed for 12 h soaked and roasted at 220 °C sorghum flakes processed at 80 rpm roller speed followed by 4.74% (wb) for the sorghum flakes processed at the same conditions and at 60 rpm roller speed.

Quality Attributes of Sorghum Flakes

Sorghum flake yield and its quality which is assessed in terms of bulk density, water absorption capacity, thickness and moisture content are presented as below.

Yield of Sorghum Flakes Obtained by Different Treatments

Yield of sorghum flakes (%) obtained by screened treatments is presented in Table 5 and Fig. 8. The highest yield in percent was obtained for T_5 treatment and lowest for T_1 treatment. It was observed that a yield of 93.27% for T_5 treatment gave the highest yield and a yield of 59.30% for T_1 treatment gave the lowest yield. It was also observed that the yield obtained for different treatments was more at 60 rpm roller speed than at 80 rpm.

It was observed that for the higher yields of flakes obtained by different treatments, the moisture content of roasted grain i.e., 33.93% (wb) for T_5 treatment could be the reason for maximum yield of flakes (93.27%) as compared to the moisture content of roasted grain i.e., 30.02% (wb) for T_1 treatment.

Final Moisture Content of Sorghum Flakes Obtained by Different Treatments

The moisture content of flakes obtained by screened treatments are presented in Table 6 and Fig. 9. Flakes moisture varied between 7.08 and 9.20% (wb) for different treatments. The highest moisture content was obtained for T_5 treatment and lowest for T_2 treatment. It was observed that a moisture content of 9.20% (wb) for T_5 treatment gave the highest and a moisture content of 7.08% (wb) for T_2 treatment. It was observed that the moisture content obtained for different treatments were more at 60 rpm roller speed than at 80 rpm.

Bulk Density of Sorghum Flakes Obtained by Different Treatments

Bulk density is an index of flake flatness and lower bulk density is a criteria for good flaking quality (Sailaja, 1992). The bulk density gives a good idea of the storage space required for a known quantity of flakes. Volume of 100 g flakes of different treatments was measured and bulk density of flakes was calculated and presented in Table 7 and Fig. 10. Bulk density in g/ml was in the range 0.317 – 0.352. The highest bulk density in g/ml was obtained for T_2 treatment and lowest for T_5 treatment. It was observed that a bulk density of 0.352 g/ml for T_2 treatment gave the highest bulk density and a bulk density of 0.317 g/ml for T_5 treatment gave the lowest bulk density. The volume of 100 g flakes for treatment T_5 was more as compared to the volume of 100 g of flakes for T_2 treatment as the thickness of flakes of T_5 treatment is less than the thickness of flakes of T_2 treatment. This increase in volume of flakes per 100 g for T_5 treatment resulted in lowest bulk density.

Water absorption Capacity of Sorghum Flakes

Water absorption capacity measures the amount of water absorbed by starch and can be used to know the extent of starch gelatinization. Water absorption capacity of flakes obtained by different treatments is presented in Table 8 and Fig. 11. Water absorption capacity in g/100 g was in the range 75.193 – 106.607. The highest water absorption capacity was obtained for T_1 treatment and lowest for T_6 treatment. It was observed that the water absorption capacity of 106.607 g/100 g for T_1 treatment gave the highest and the water absorption capacity of 52.477 g/100 g for T_6 treatment gave the lowest. The difference in water absorption capacity might be attributed to the surface of flakes, which can imbibe water into the flake matrix differently.

Sorghum flakes of different treatments were inspected and 20 flakes were chosen for measuring thickness (Gates, 2008). Thickness of sorghum flakes obtained by different treatments are presented in Table 9 and Fig. 12. Flake thickness was in the range of 0.757 to 0.947 mm, which was greater than the 0.1 mm roller gap. The highest thickness was obtained for T_6 treatment and lowest for T_1 treatment. It was observed that a thickness of 0,947 mm for T_6 treatment gave the highest thickness and a thickness of 0.757 mm for T_1 treatment gave the lowest thickness.

CONCLUSION

1. The highest yield of 93.27% percent was obtained for flakes processed by 36 h soaking, open pan roasting at 125±2 °C and 60 rpm roller speed and lowest yield of 59.30% for 24 h soaking, open pan roasting at 125±2 °C and 80 rpm roller speed. It was also observed that the yield obtained for different treatments was more at 60 rpm roller speed than at 80 rpm.
2. It was observed that a moisture content of 9.20% (wb) for flakes processed by 36 h soaking, open pan roasting at 125±2 °C and 60 rpm roller speed gave the highest and a lowest moisture content of 7.08% (wb) for flakes processed by 24 h soaking, open pan roasting at 125±2 °C and 80 rpm roller speed.
3. It was observed that a bulk density of 0.352 g/ml for flakes processed by 24 h soaking, open pan roasting at 125±2 °C and 80 rpm roller speed gave the highest and a bulk density of 0.317 g/ml for flakes processed by 36 h soaking, open pan roasting at 125±2 °C and 60 rpm roller speed gave the lowest.
4. It was observed that the water absorption capacity of 106.607 g/100 g for flakes processed by 24 h soaking, open pan roasting at 125±2 °C and 60 rpm roller speed gave the highest and the water absorption capacity of 52.477 g/100 g for flakes processed by 36 h soaking, open pan roasting at 125±2 °C and 80 rpm roller speed gave the lowest.
5. It was observed that a thickness of 0.947 mm for flakes processed by 36 h soaking, open pan roasting at 125±2 °C and 80 rpm roller speed gave the highest and a thickness of 0.757 mm for flakes processed by 24 h soaking, open pan roasting at 125±2 °C and 60 rpm roller speed gave the lowest.
6. Based on the highest yield and lowest bulk density of flakes it can be concluded that 36 h soaking time, pan roasting at 125±2 °C, roller flaking at 60 rpm and with 0.1 mm gap between the rollers were the process and machine parameters optimized.

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